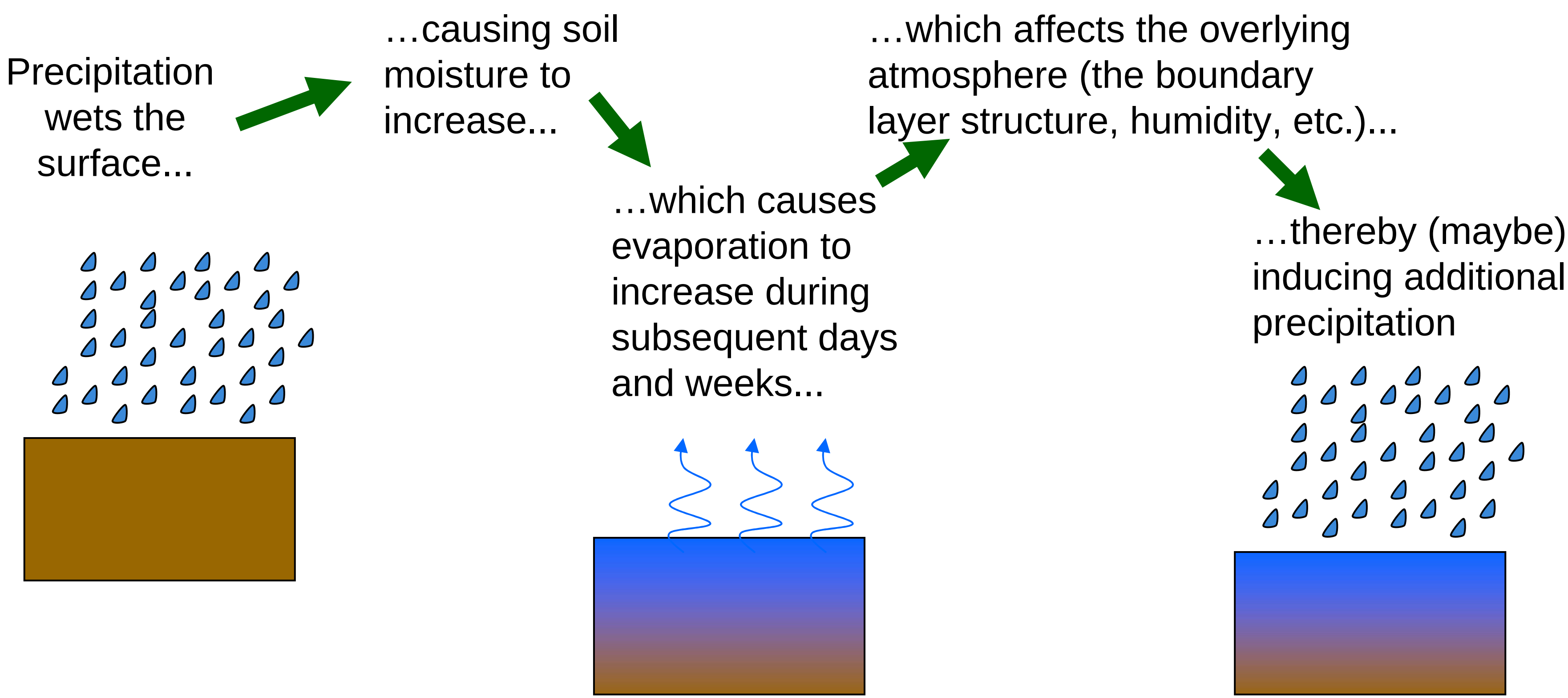
Assimilation of AMSR-E data and application to the initialization of soil moisture reservoirs in a seasonal forecasting system

Rolf Reichle[1,2] (PI), X. Zhan[4], R. Koster[2], P. Houser[5], J. Bacmeister[1,2]

Motivation	Seasonal climate prediction & land initialization
Results	Global assimilation of **SMMR** retrievals
In Progress	Assimilation of **AMSR-E** retrievals

1 – GEST, University of Maryland, Baltimore County
2 – Global Modeling and Assimilation Office, NASA
3 – Hydrological Sciences Branch, NASA-GSFC
4 – USDA
5 – George Mason University

A simple view of land-atmosphere feedback



Perhaps such feedback contributes to predictability?

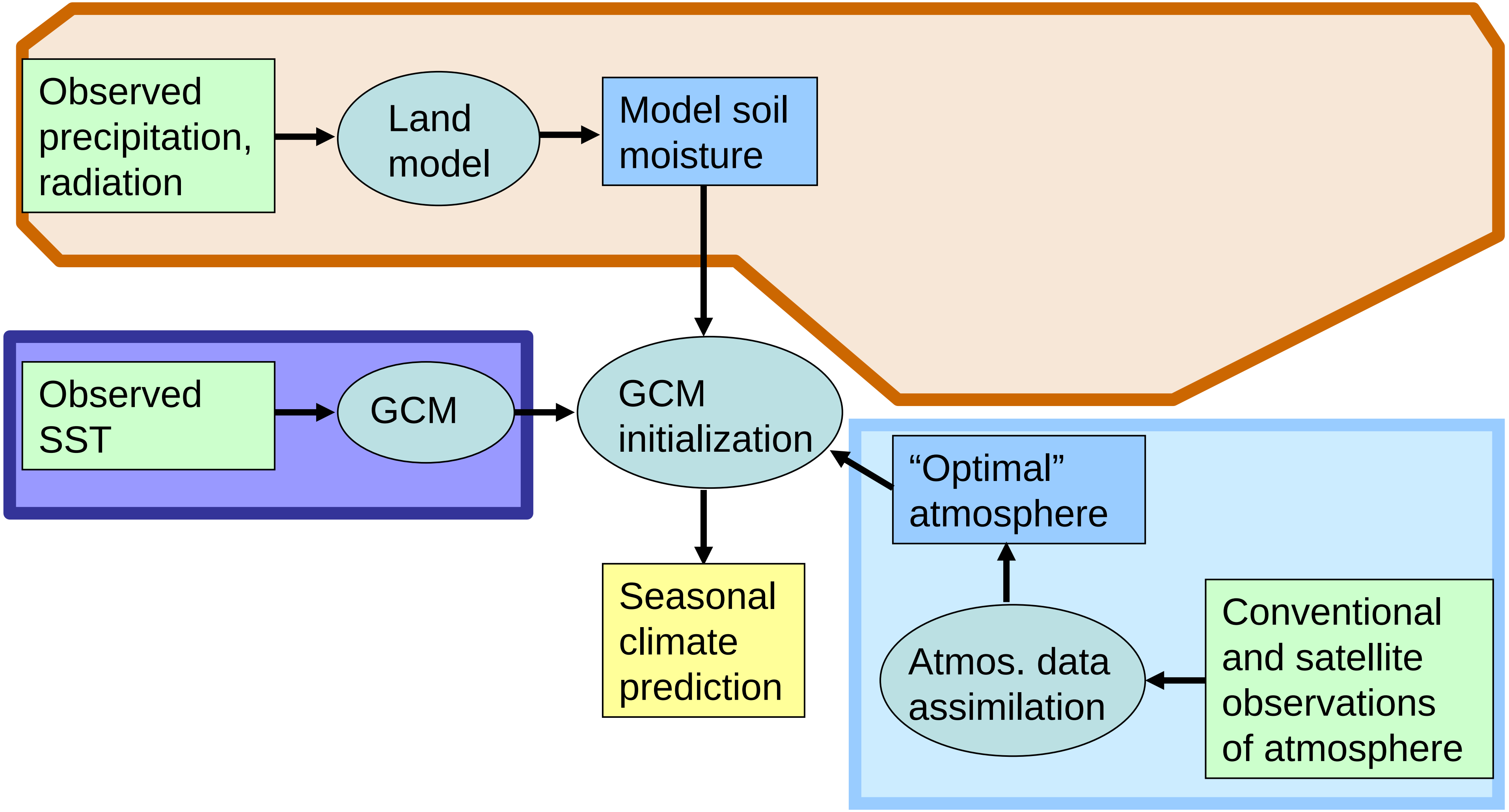
Two things must happen:

1. A soil moisture anomaly must be “remembered” into the forecast period.
2. The atmosphere must respond predictably to soil moisture anomalies.

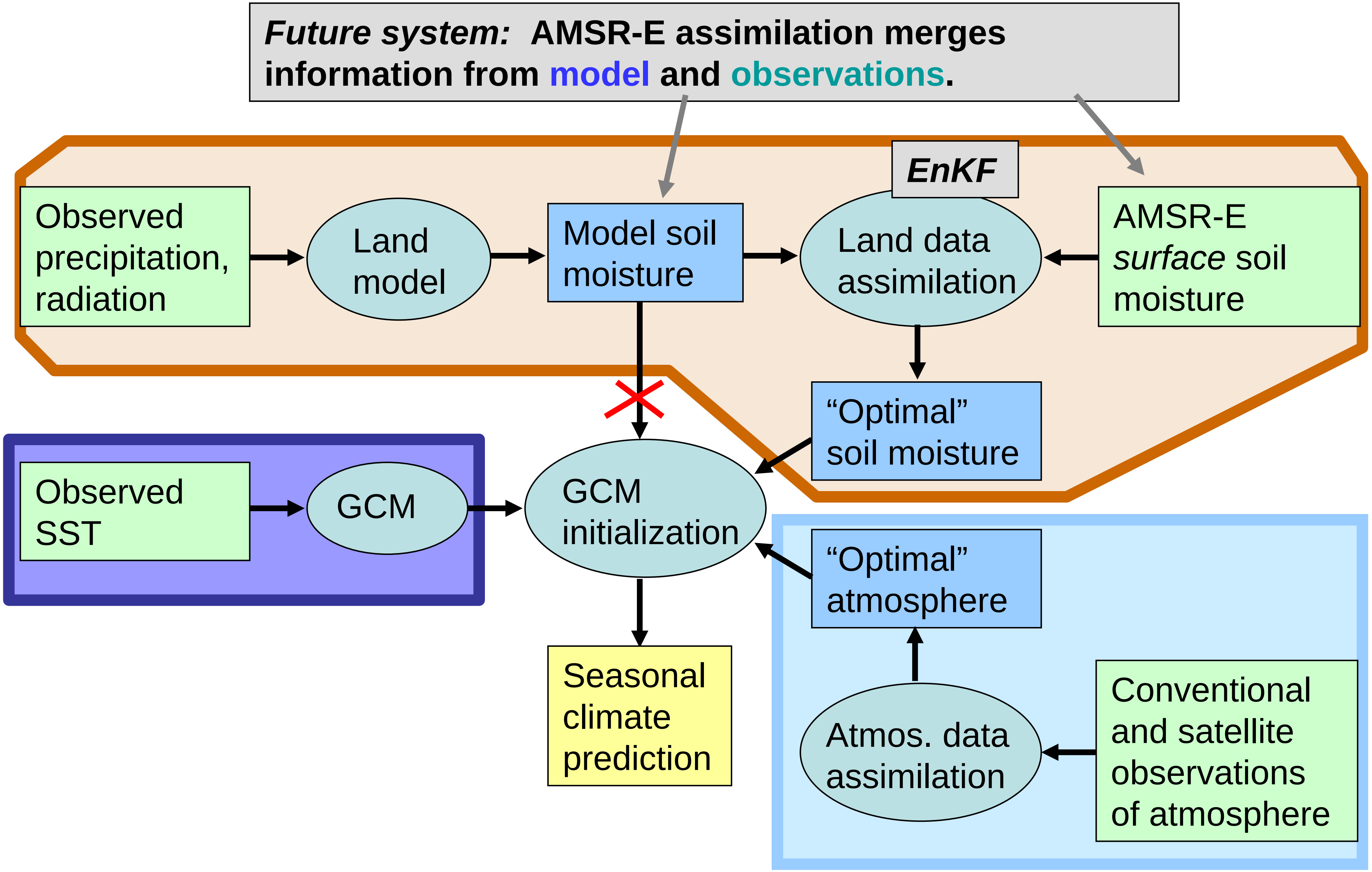
e.g. Koster et al., *J. Hydromet.*, 2004; Koster et al., *Science, 2004*

NASA seasonal forecast initialization

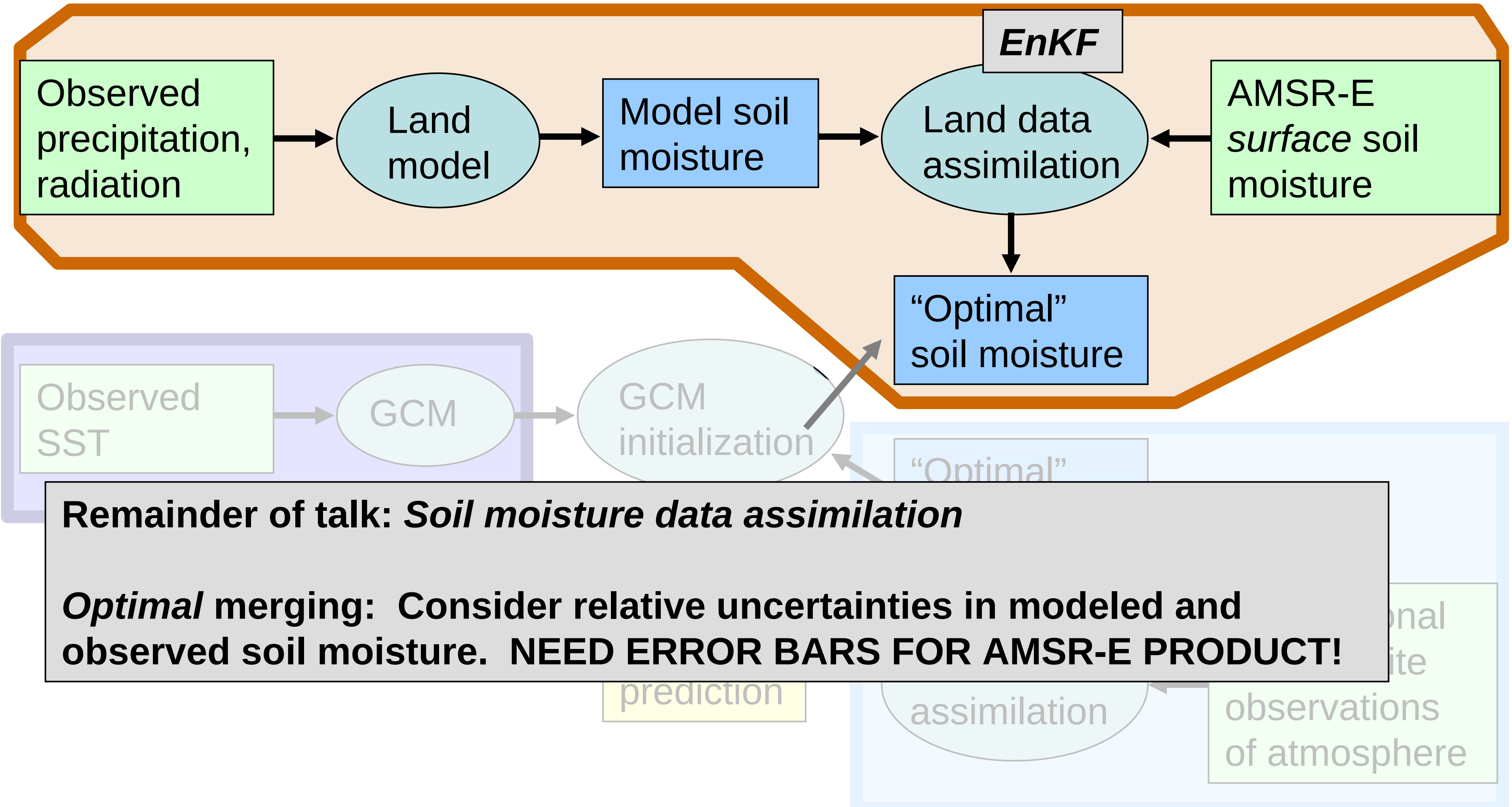
Operational system (since April 2004)



NASA seasonal forecast initialization



Soil moisture assimilation



Remainder of talk: *Soil moisture data assimilation*

***Optimal* merging: Consider relative uncertainties in modeled and observed soil moisture. NEED ERROR BARS FOR AMSR-E PRODUCT!**

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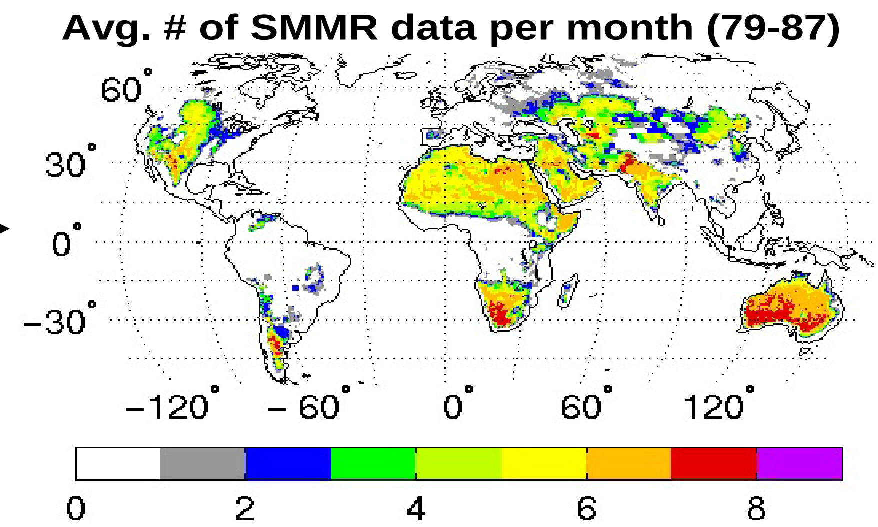
Results from SMMR

ASSIMILATE

1. SMMR *(1978-87)*
Satellite retrievals (Owe et al.)
(upper 1.25cm, ~140km, ~3 days)

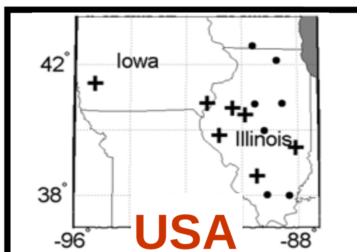


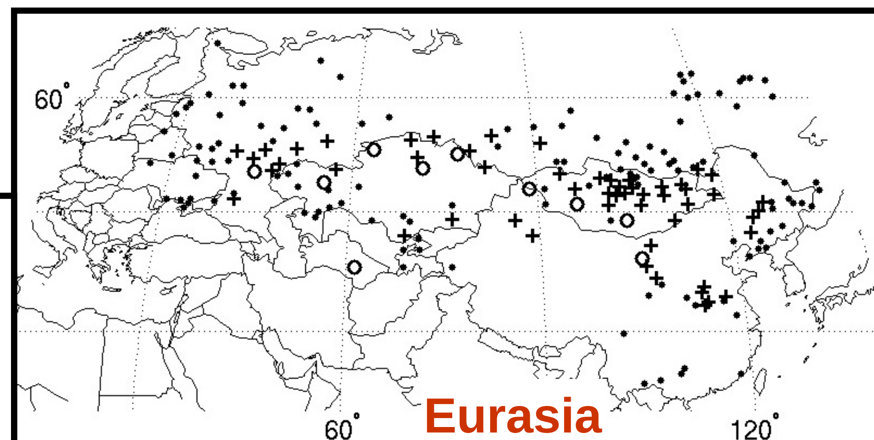
Not available under dense vegetation, close to water surfaces, in frozen soil.

2. Catchment *Model (CLSM) (1979-93)*
Model results with observation-corrected meteorological forcing (Berg, Famiglietti, et al.)
(upper 2cm, ~40…150km, 6h)

VALIDATE

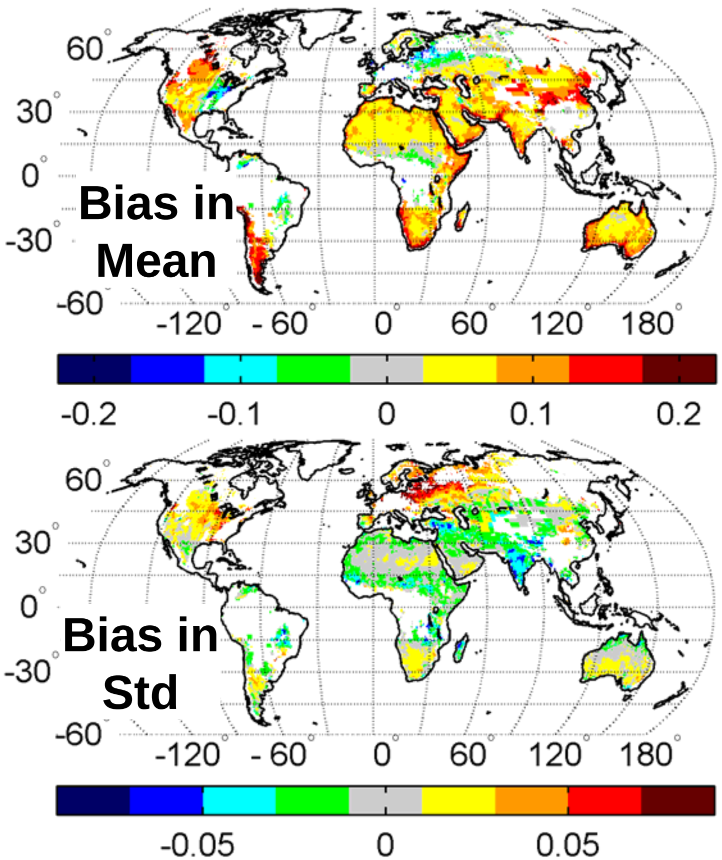
3. Ground data
Global Soil Moisture Data Bank (GSMDB; Robock et al)
(upper 5…10cm, point scale, ~10 days)
~200 stations total
~70 included in analysis





Global soil moisture climatology?

Bias between model and SMMR soil moisture

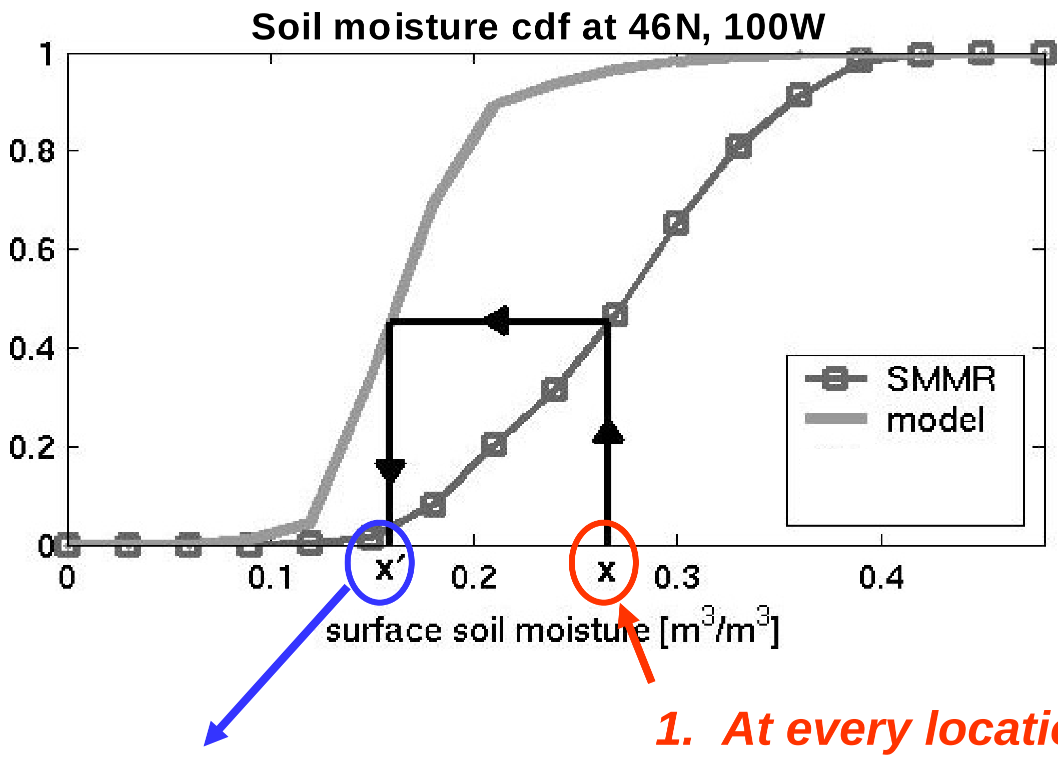


1. **Strong global and regional biases in all moments.**
2. **Satellite and model agree equally well (or poorly…) with ground observations $\Rightarrow$ no agreed climatology.**
3. **For seasonal forecasts, need only normalized anomalies.**

$\Rightarrow$ ***Scale satellite data before assimilation into a model.***

Reichle et al., *J. Hydromet*, 2004

Soil moisture scaling for data assimilation



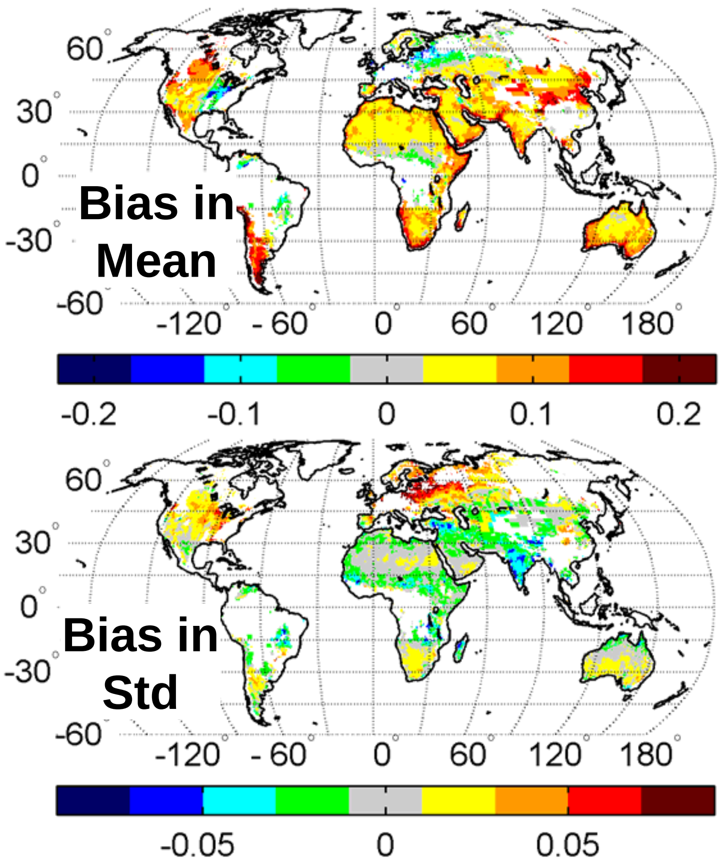
1. At every location, find percentile of a given satellite measurement on the satellite's climatological cumulative distribution function (CDF).

2. Find soil moisture that produces the same CDF value on the corresponding model CDF ⇒ "scaled" satellite measurement for assimilation.

In short: Assimilate percentiles.

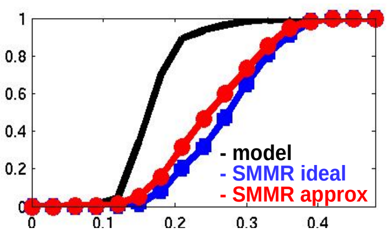
Soil moisture scaling for data assimilation

***ORIGINAL* 9-year data sets**
(model & SMMR soil moisture)

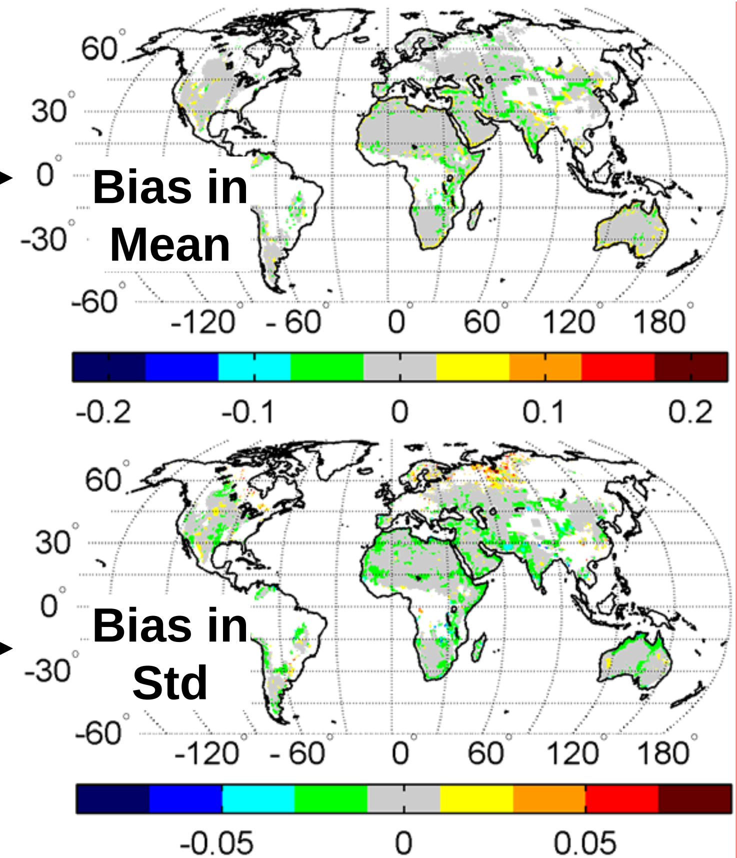


Reichle et al., *J. Hydromet,* 2004

CDF scaling based on **1 year** of satellite data



***SCALED* 9-year data sets**
(model & SMMR soil moisture)



Reichle & Koster, *GRL* 2004

1 year of satellite data sufficient for considerable reduction in long-term bias.

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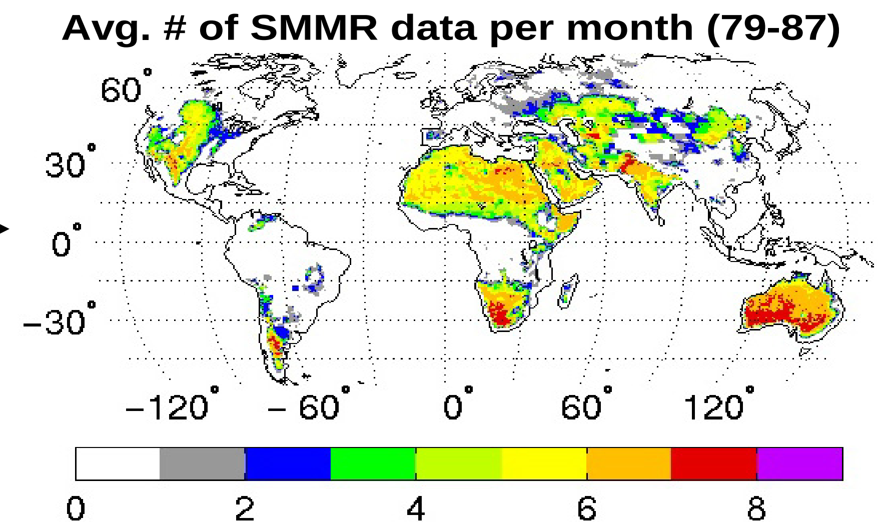

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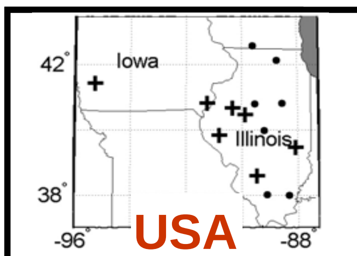

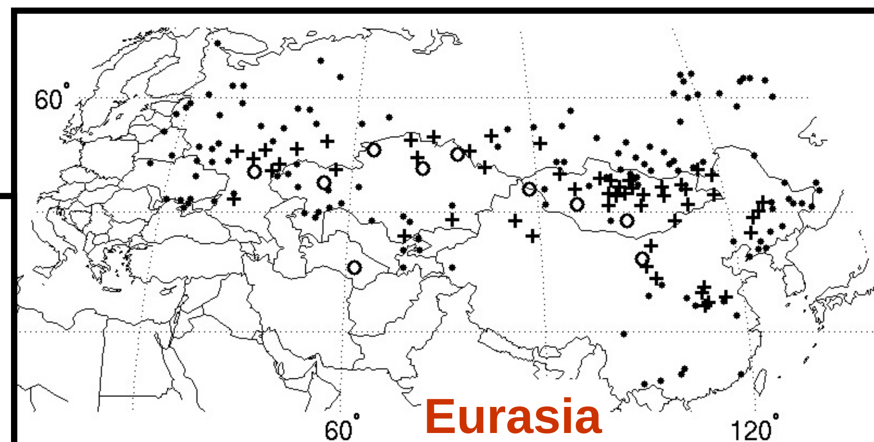

Validation against in situ data

		Time series correlation coeff. with in situ data [-] (with 95% confidence interval)			Confidence levels: Improvement of assimilation over	
	N	**SMMR**	**Model**	**Assim.**	**SMMR**	**Model**
Surface soil moisture	77	**.44±.03**	**.43±.03**	**.50±.03**	**99.7%**	**99.9%**
Surface anomalies	66	**.32±.03**	**.36±.03**	**.43±.03**	**99.9%**	**99.9%**
Root zone soil moisture	59	**n/a**	**.46±.03**	**.50±.03**	**n/a**	**97%**
Root zone anomalies	33	**n/a**	**.32±.05**	**.35±.05**	**n/a**	**80%**

Assimilation product agrees better with ground data than SMMR or model alone.

Modest increase may be close to maximum possible with *imperfect* in situ data.
Modern satellite (AMSR-E), forcing, and validation data should increase skill.

Reichle & Koster, *GRL* 2005

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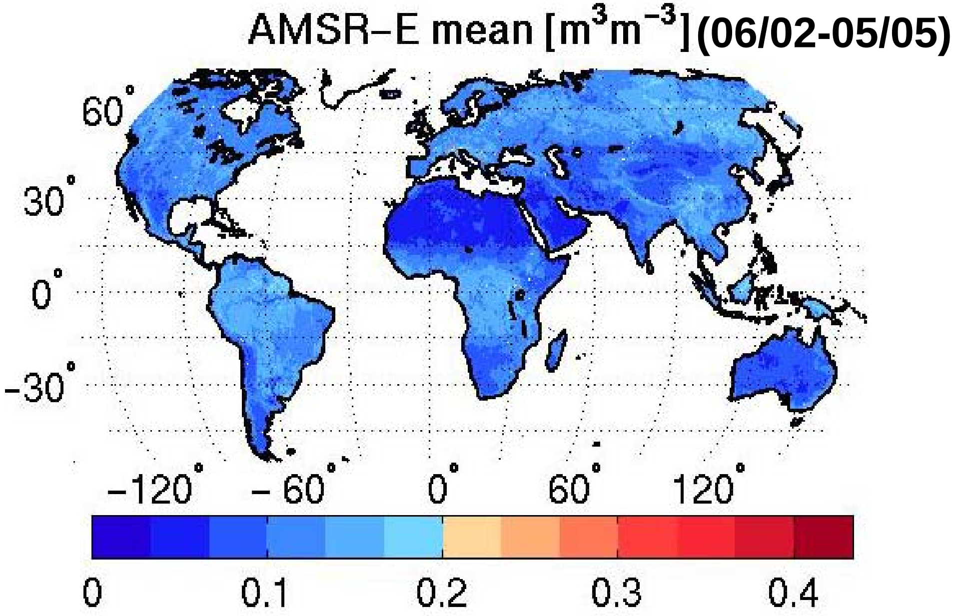
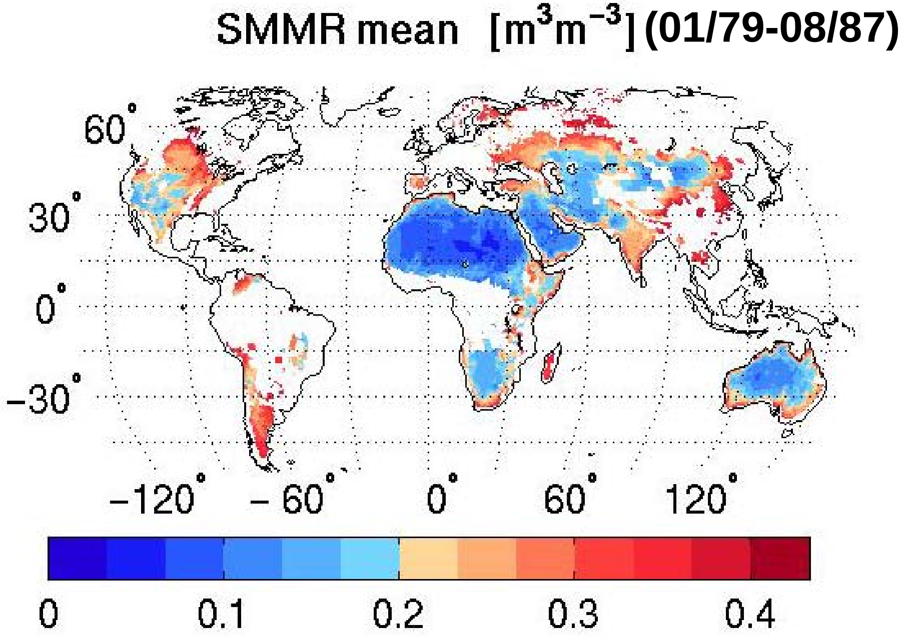
Time series stats of AMSR-E and SMMR retrievals





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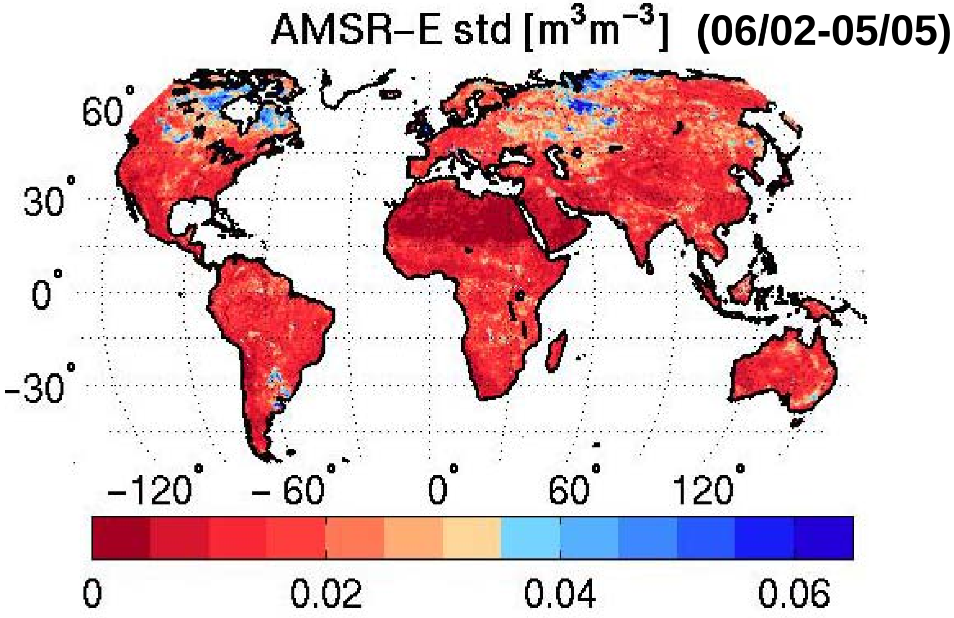

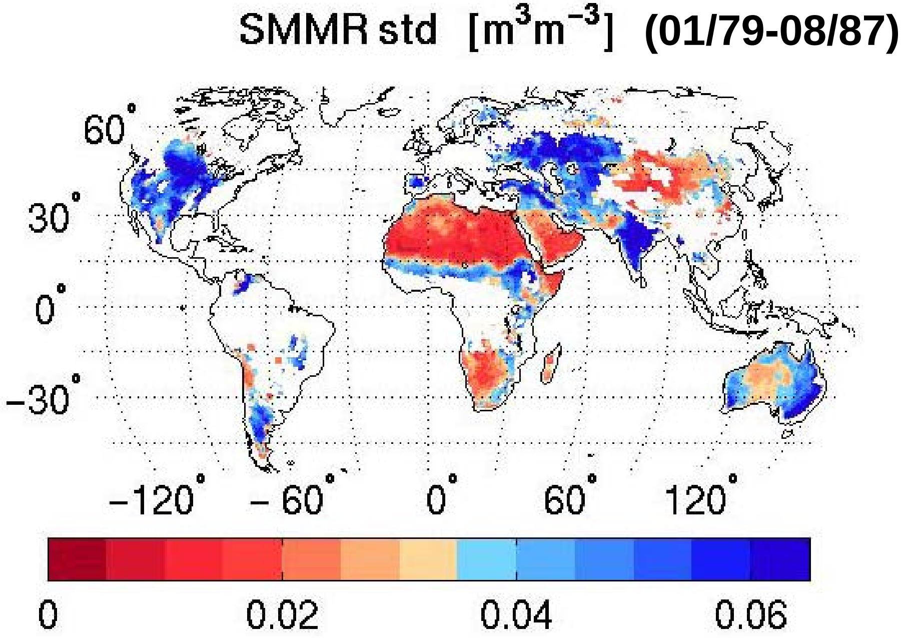

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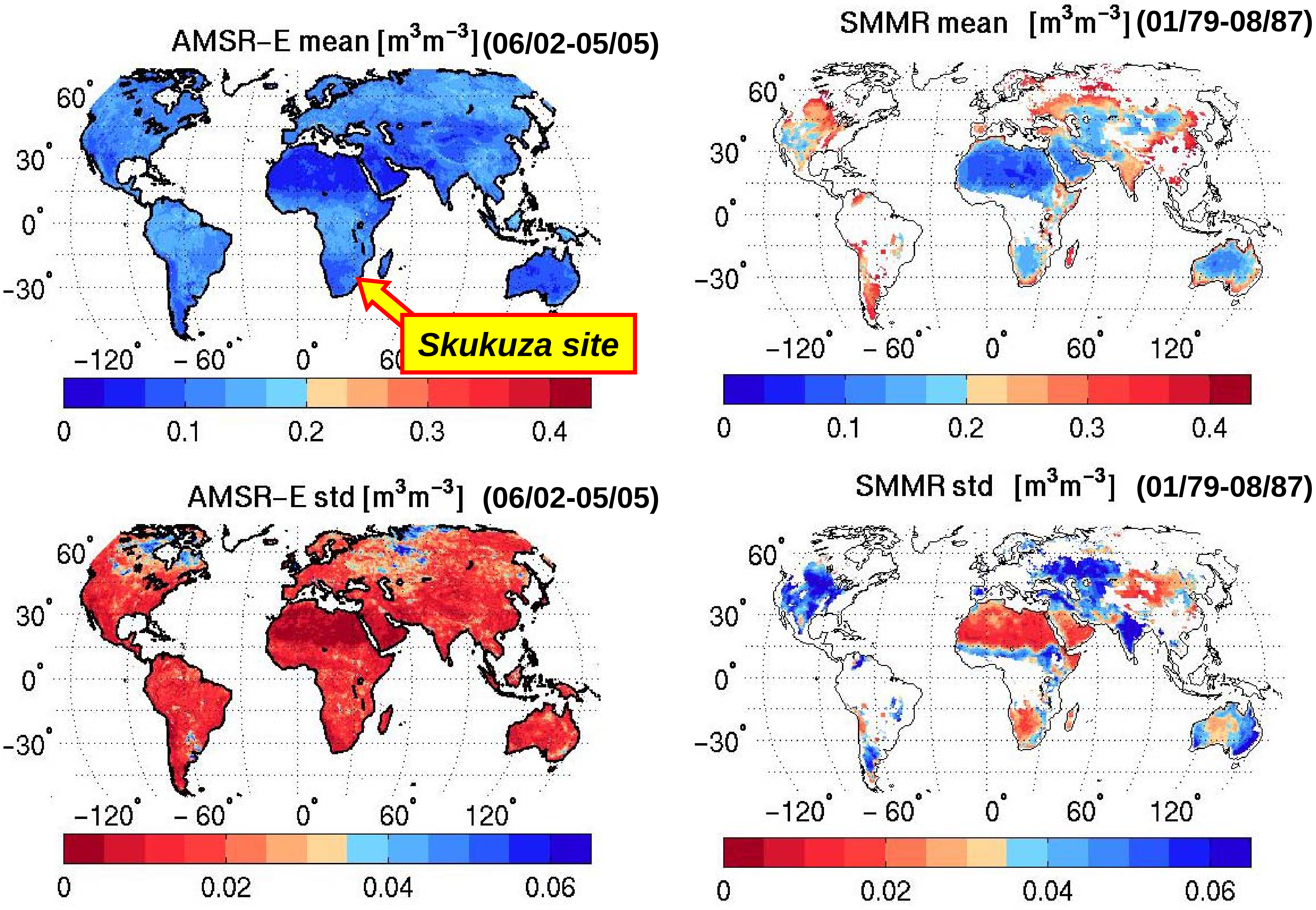
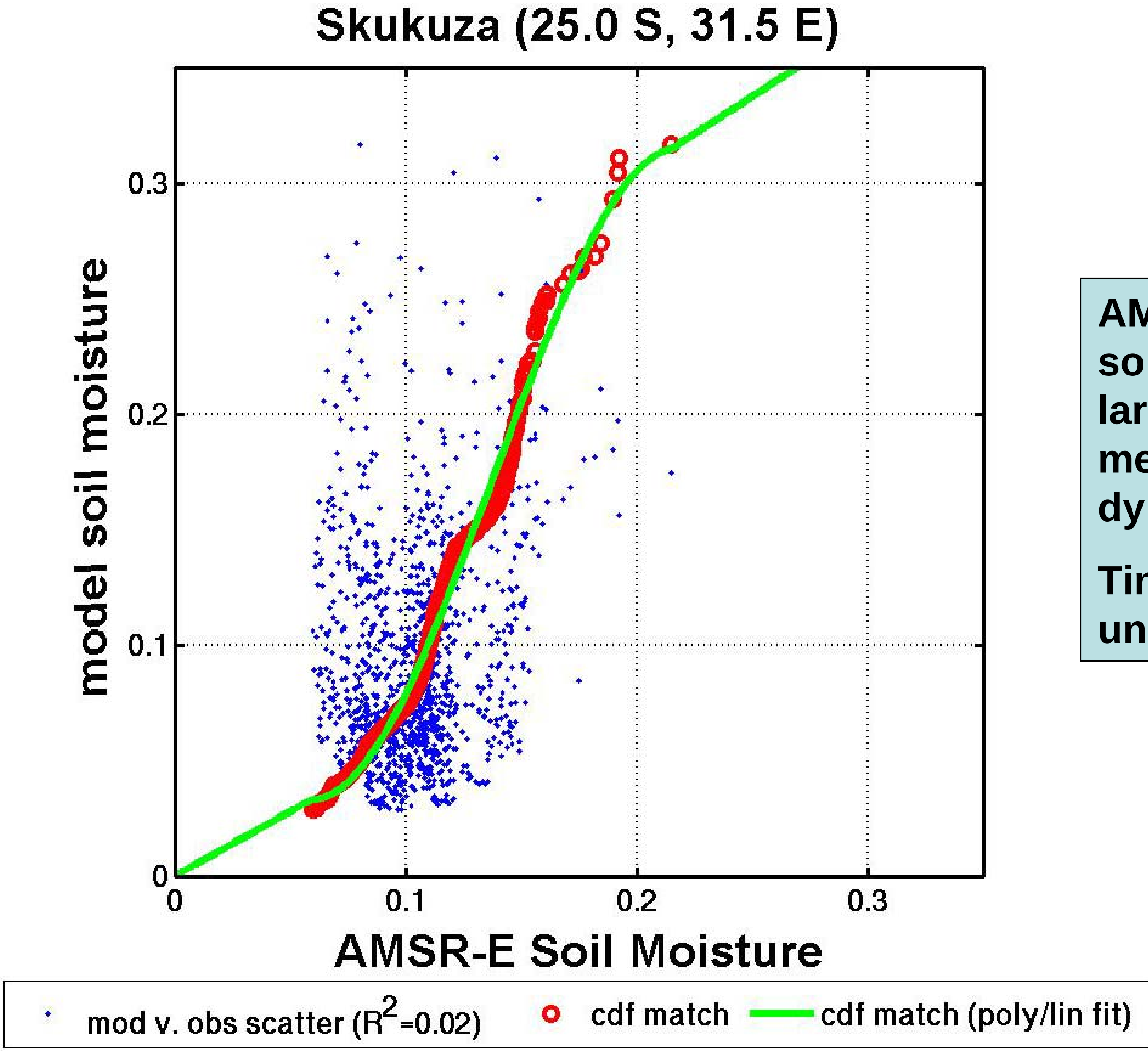


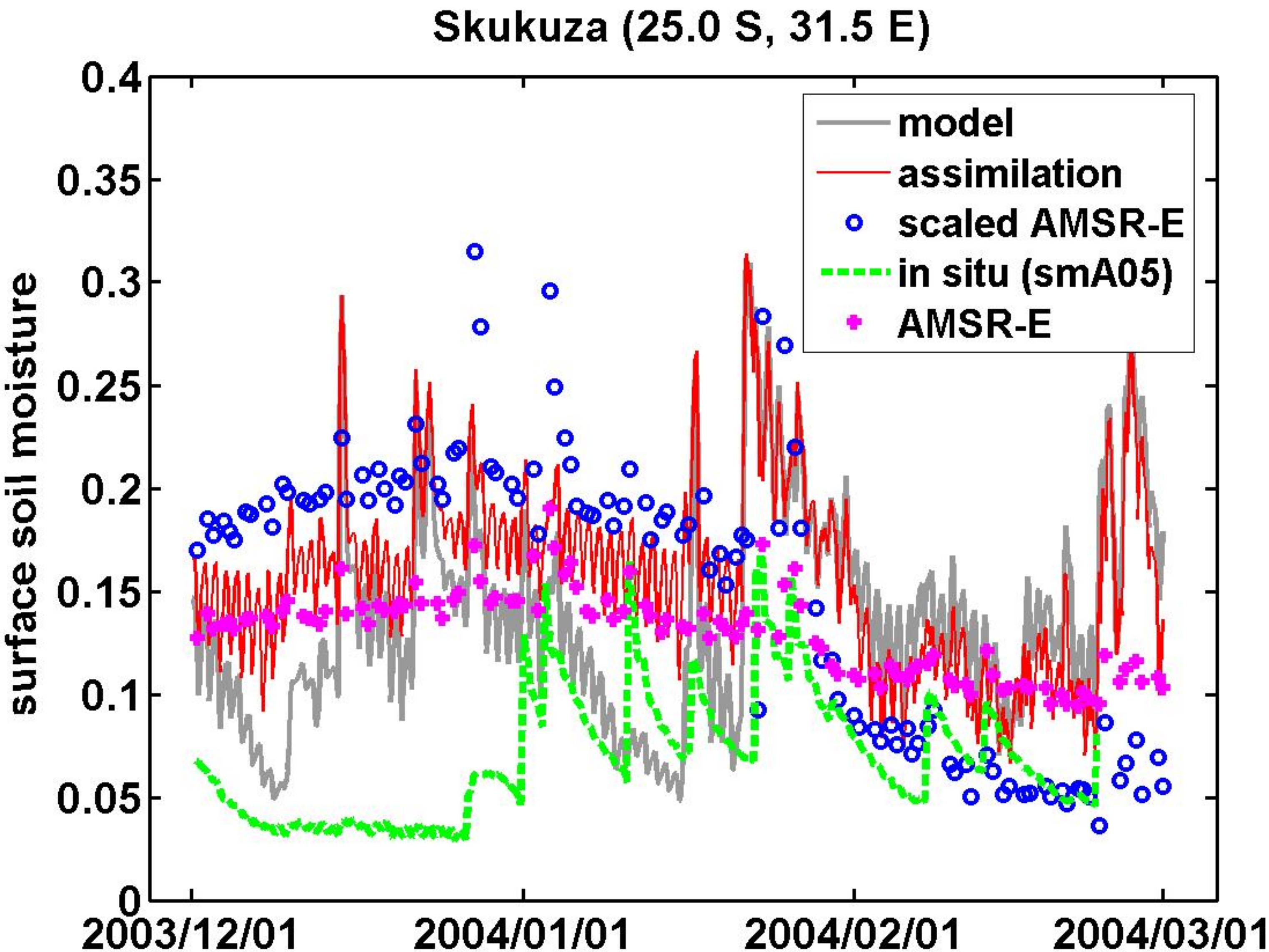
Comparison of AMSR-E and model soil moisture



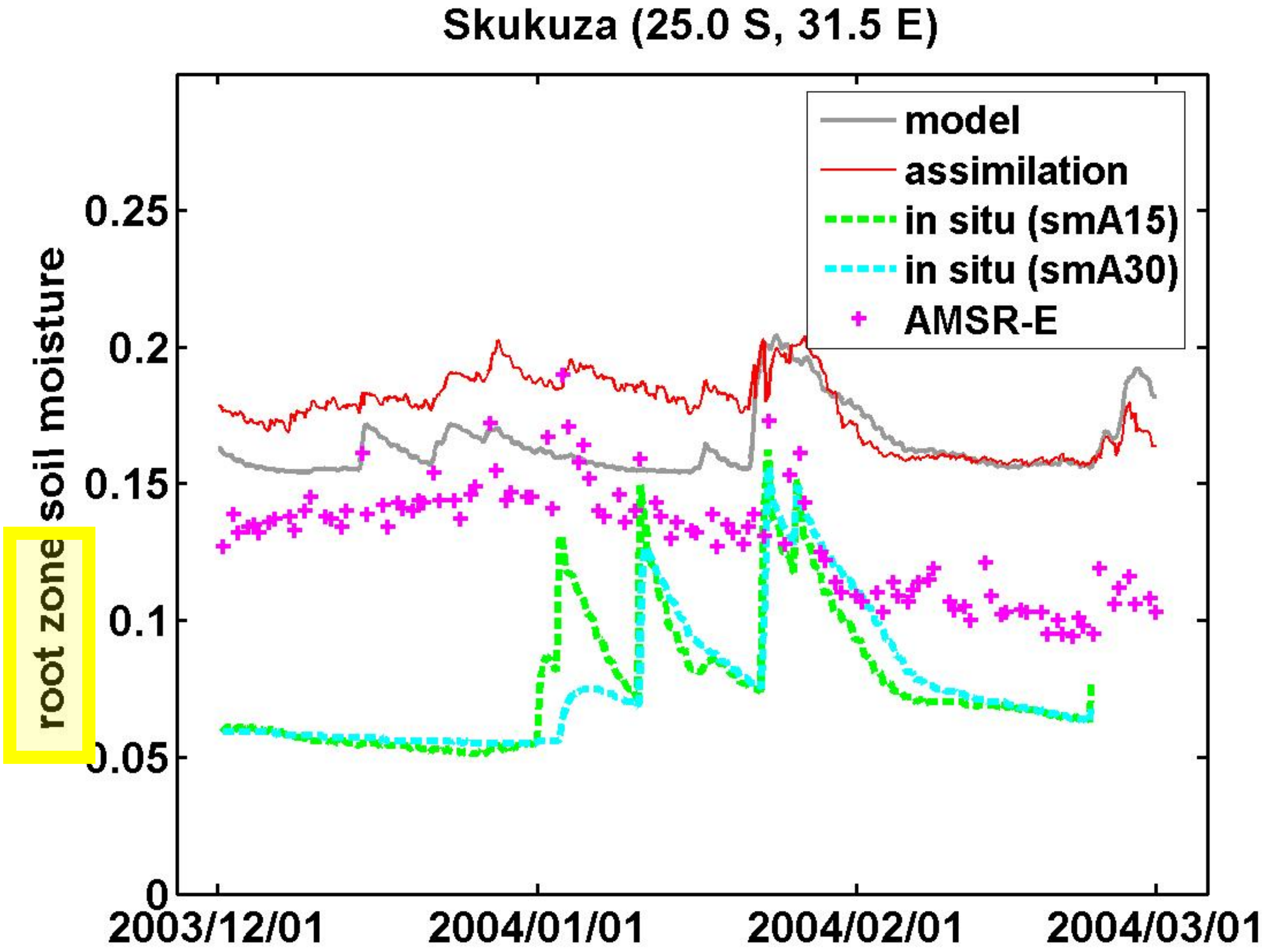
AMSR-E and model soil moisture show large differences in mean, variability, and dynamic range.

Time series are uncorrelated (R^2=.02).

Assimilation of AMSR-E soil moisture



Assimilation of AMSR-E soil moisture



Validation against in situ data

		Time series correlation coeff. with in situ data [-] (*Jun 02 – Apr 05, monthly average*)		
	N	**AMSR-E**	**Model**	**Assim.**
Surface soil moisture	1	**-.04**	**.56**	**.17**
Root zone soil moisture	1	**n/a**	**.33**	**.08**

For this site, the assimilation product does NOT agree better with ground data than model alone.

Biggest concern are AMSR-E retrievals.

Conclusions

Results:

Improved land initialization enhances sub-seasonal prediction skill.

SMMR assimilation improves land initialization.

AMSR-E assimilation system implemented.

AMSR-E assimilation results undergoing validation.

Biggest concern at this time are AMSR-E soil moisture retrievals.

Outlook:

Continue assessment of soil moisture estimates.

Impact of SMMR and AMSR-E assimilation on seasonal predictions.

THE END.

Work Plan

TASK I – Preparation of input data sets.

TASK II – Assimilation and analysis of soil moisture data

Prepare four different *soil moisture datasets*: Integrate land model with

1. GCM-produced precip./radiation (GCM forced with observed SST)
2. observed precip./radiation
3. GCM-produced precip./radiation + assimilation of AMSR-E soil moisture
4. observed precip./radiation + assimilation of AMSR-E soil moisture

Assess impact of AMSR-E data on soil moisture estimation.

TASK III – Experimental prediction

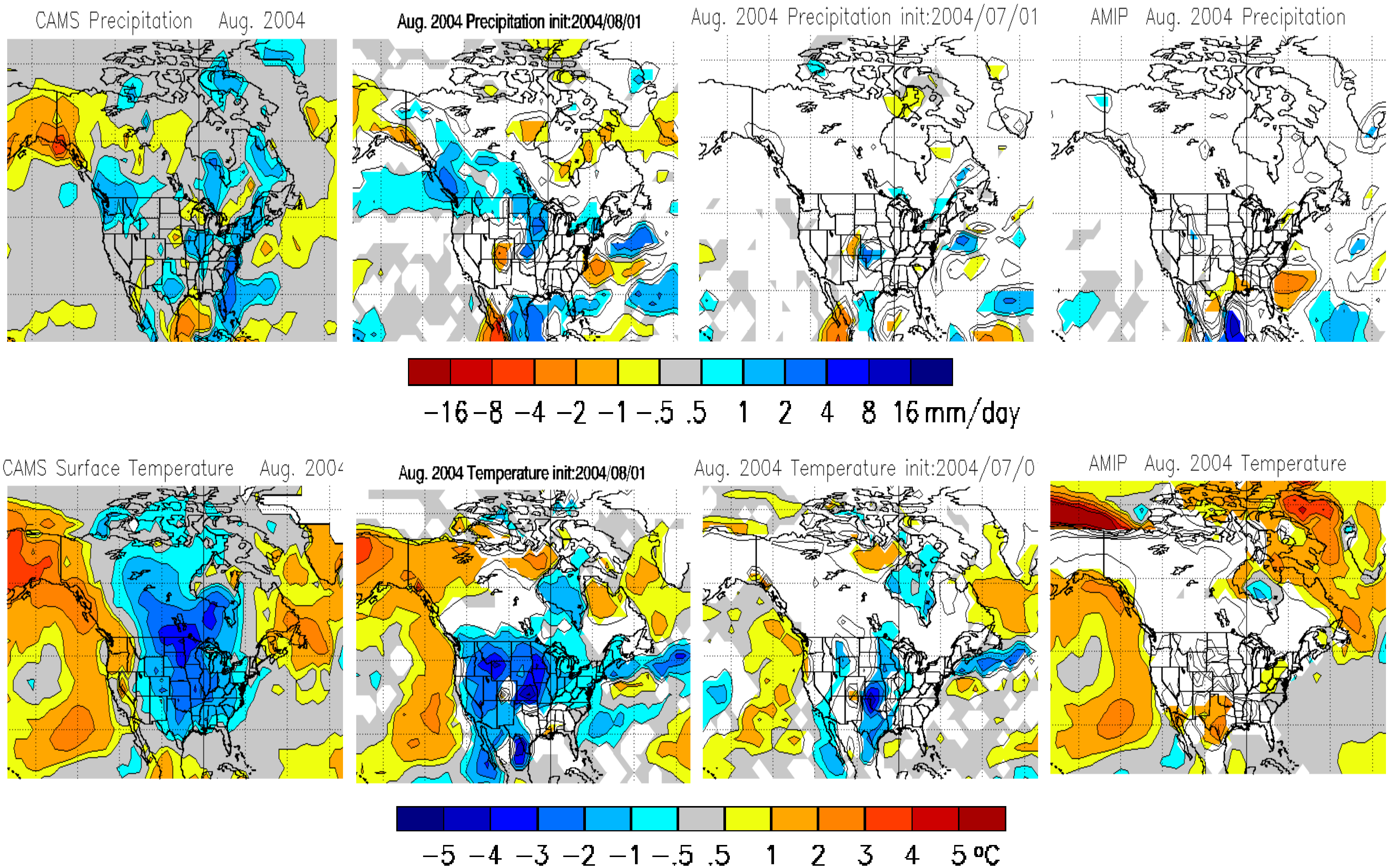
Ensemble *seasonal forecast experiments* with initial conditions from TASK II.

Assess impact of observed precip./radiation and AMSR-E assimilation on seasonal forecasts.

Establish routine AMSR-E land assimilation in operational GMAO seasonal forecasting system.

Sample NASA forecast – August 2004

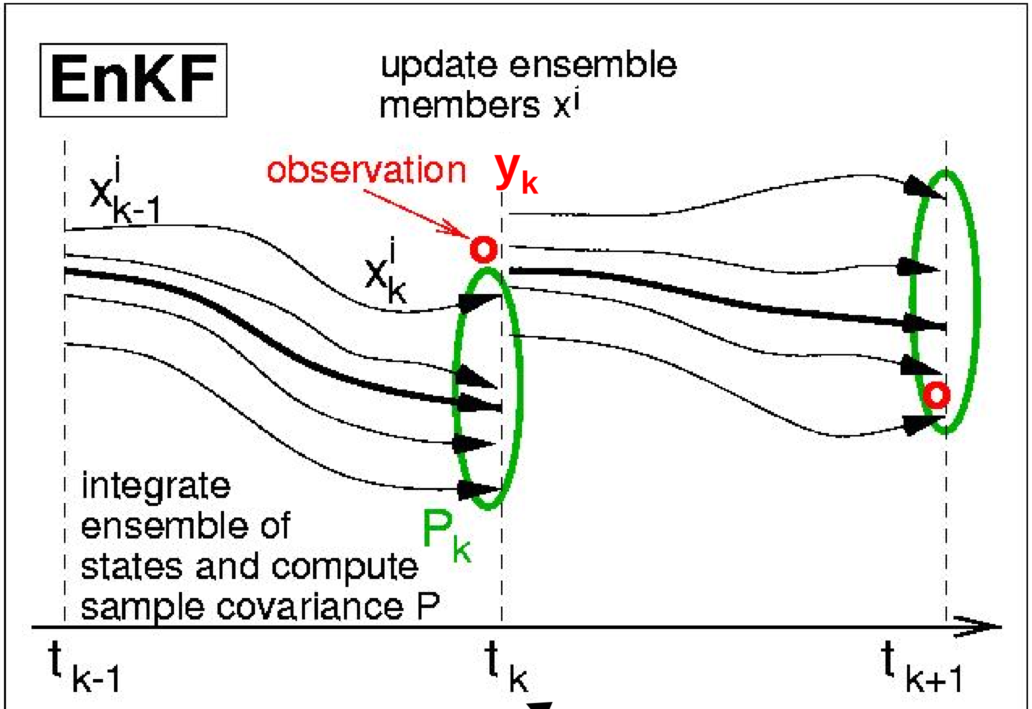
Validation (CAMS) | **Forecast 1st month** | **Forecast 2nd month** | **AMIP ensemble (uses only SST information)**



Precipitation

Temperature

Soil moisture assimilation



Nonlinearly propagates ensemble of model trajectories.

Can account for wide range of model errors (incl. non-additive).

Approx.: **Ensemble size.**

Linearized update.

$\mathbf{x_k^i}$	state vector (eg soil moisture)
$\mathbf{P_k}$	state error covariance
$\mathbf{R_k}$	observation error covariance

Propagation $\mathbf{t_{k-1}}$ to $\mathbf{t_k}$:

$$\mathbf{x_k^{i+} = f(x_{k-1}^{i-}) + w_k^i}$$

w = model error

Update at $\mathbf{t_k}$:

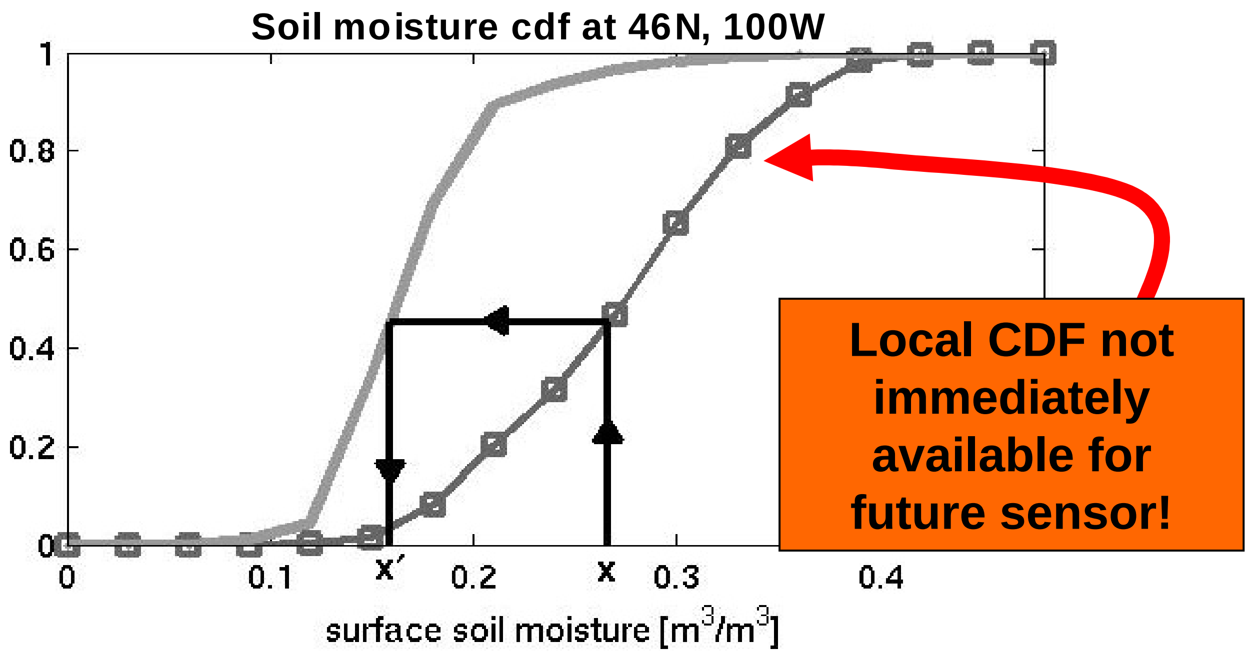
$$\mathbf{x_k^{i+} = x_k^{i-} + K_k(y_k^i - x_k^{i-})}$$

for each ensemble member i=1…N

$$\mathbf{K_k = P_k (P_k + R_k)^{-1}}$$

with $\mathbf{P_k}$ computed from ensemble spread

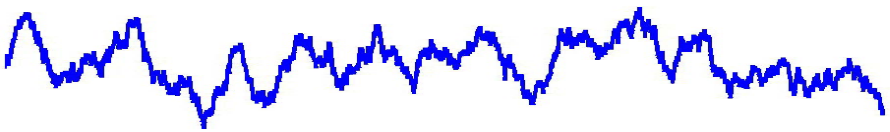
Soil moisture scaling for data assimilation



Solution:

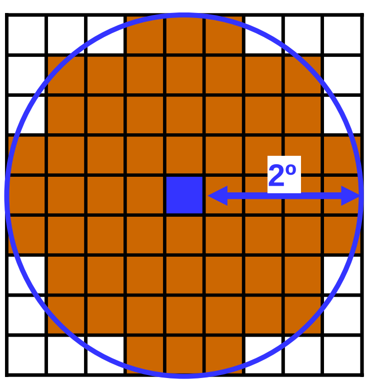
Ergodic substitution of variability in space for variability in time.

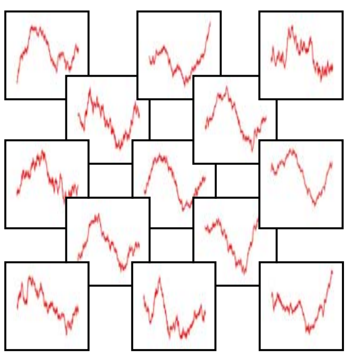
Soil moisture scaling for data assimilation

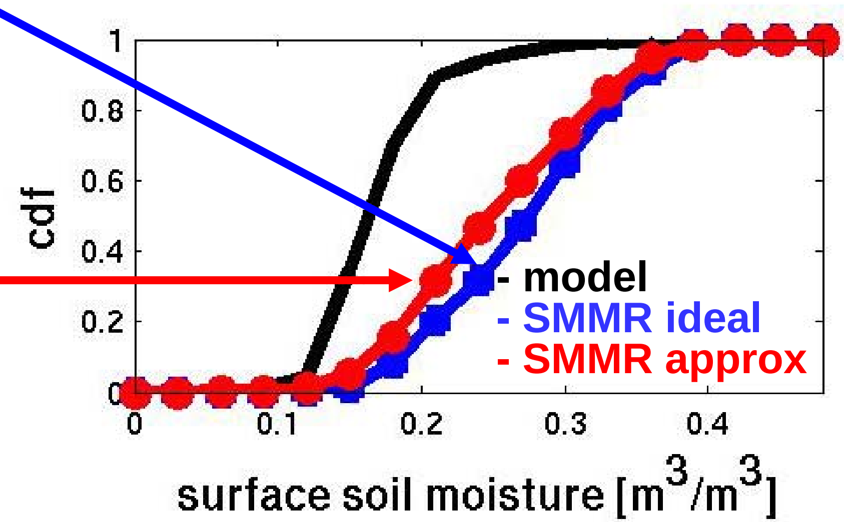


Ideally, compute local CDF from long time series at point of interest.

Approximate CDF from many 1-year time series at grid points within 2º from point of interest.

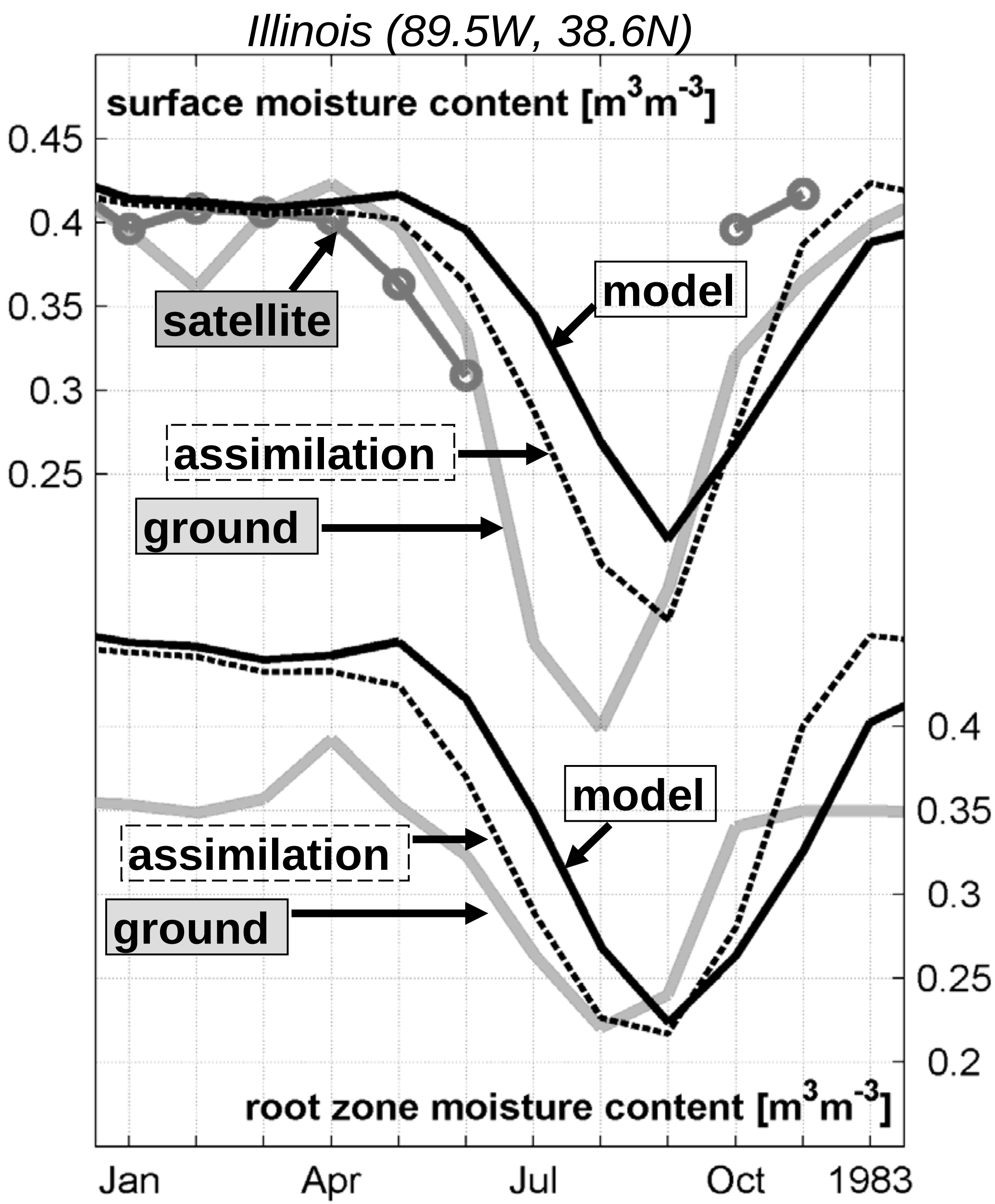






A single year of satellite data is sufficient for a good approximation of the ideal CDF.

Validation against in situ data



SMMR assimilation product has improved phase of annual cycle.

Reichle & Koster, *GRL* 2005